Studies on Radiation Level, Radionuclides and Trace Elements Concentration in Environmental Matrices around Gogi Uranium Mining Region

A Synopsis of the Thesis to be submitted to the Mangalore University for the Award of the Degree of Doctor of Philosophy in Physics

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Abstract

Detailed studies on radiation level, radionuclides and trace elements concentration in environmental matrices around Gogi uranium mining region were carried out, which has been identified as a prospective uranium mining region by Atomic Mineral Department (AMD), Department of Atomic Energy (DAE). For the sampling purpose, the region was divided into 3 different zones (0-5 km Core zone, 5-15 km Buffer zone I, and 15-30 km Buffer zone II), with the proposed mining site (Gogi) as the centre of all the zones. Sampling locations are identified in such a way that they are spread uniformly in all the directions in different zones so that entire region is covered under the study. In-situ ambient gamma absorbed dose rates were carried out using GM survey meter and the long-term instantaneous measurement of gamma absorbed dose rates were measured using the thermoluminescent dosimeters (TLDs). A total of 39 sampling stations were identified for collecting terrestrial, aquatic, and atmospheric samples were collected during different seasons of the year continuously during June 2010 to November 2012 following standard procedures as outlined in EML, IAEA and BARC procedure manual. Radionuclide concentrations in the soil and vegetable samples were measured by gamma spectrometers employing either a 42% (n-type) or a 38% (p-type) HPGe gamma spectrometer. A comparative study of gamma absorbed dose rates measured by GM survey meter, TLDs and soil radioactivity also carried out. Activity concentration of ^{210}Po was determined by chemical deposition onto silver disc followed by ZnS(Ag) alpha counting. Long-term measurements of indoor ^{222}Rn and ^{220}Rn concentration was carried using pinhole SSNTD dosimeters and the progeny concentrations were measured using Direct Radon Progeny Sensors (DRPS) and Direct Thoron Progeny Sensors (DTPS) developed by BARC. Short-term screening measurements of ^{222}Rn was performed using AlphaGuard system. Radionuclide concentrations in air were measured by using high volume air sampler and analysing the filter paper by gamma spectrometry. Uranium concentration in water samples was measured by laser fluorimetry, ^{226}Ra concentration in water was measured by pre-concentration method using MnO_2 powder followed by HPGe gamma spectrometry and ^{222}Rn concentration was measured by emanometry method followed by ZnS(Ag) alpha counting. Trace elements concentrations in the soil and vegetable samples were determined by digesting the sample using microwave digestion system and subsequent determination by Atomic Absorption Spectrometry (AAS). Concentration of stable elements in water samples were also measured by using AAS.

The median value of indoor gamma absorbed dose rates was found to be 124 nGy h^{-1} and the outdoor dose was 118 nGy h^{-1}. The median value of the gamma dose observed for the Gogi region was higher when compared to the worldwide as well as all India average value.

The median values of activity concentrations of ^{40}K, ^{232}Th, ^{238}U, ^{226}Ra,^{210}Pb, and ^{137}Cs in the soil samples were found to be 778.9 Bq kg^{-1}, 84.4 Bq kg^{-1}, 43.6 Bq kg^{-1}, 33.3 Bq kg^{-1}, 44.3 Bq kg^{-1} and 0.9 Bq kg^{-1}, respectively. The activity concentration of ^{210}Po in the soil varied in the range of 21.0-190.7 Bq kg^{-1} with a median value of 48.1 Bq kg^{-1}. The analyses of the soil samples for the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K revealed highly non-uniform distribution of these radionuclides in Gogi region with activity concentrations in the soil varying significantly within a small area, which is due to the highly localised uranium mineralisation. The mean value of activity concentration of ^{232}Th and ^{40}K for the entire study region were higher when compared to the average value reported for India and also worldwide average values. The indoor equilibrium equivalent thoron concentration (EETC) and equilibrium equivalent radon concentration (EERC) were 1.3 Bq m^{-3} and 8.3 Bq m^{-3}, respectively. The indoor ^{222}Rn and ^{220}Rn concentrations, measured using pinhole dosimeters, were found to be 30.4 Bq m^{-3} and 14.9 Bq m^{-3}, respectively. The activity concentrations of ^{7}Be, ^{40}K, ^{232}Th, ^{226}Ra and ^{210}Pb in the air samples had median values of 3.7 mBq m^{-3}, 3.1 mBq m^{-3}, 1.8 mBq m^{-3}, 0.3 mBq m^{-3} and 1.2 mBq m^{-3}, respectively. The uranium concentration in the water samples varied in the range of <2.4 – 33199 mBq L^{-1} with a median value of 115.1 mBq L^{-1}. The ^{226}Ra activity concentration in the water samples varied in the range of 19.5 - 10505 mBq L^{-1} with the median value of 52.6 mBq L^{-1}. The ^{222}Rn activity concentration in the water samples varied in the range of 0.4-2115 Bq L^{-1} with a median value of 17.4 Bq L^{-1} for different sources of water (tube-well, open-well, stream/river, and lake). The activity concentrations of ^{238}U, ^{226}Ra and ^{222}Rn in some of the tube-well water samples were higher when compared to the values reported for other regions of India. Since the uranium mining has not yet started in Gogi region and therefore the observed higher activity concentrations of ^{238}U, ^{226}Ra and ^{222}Rn in the tube-wells due to the high uranium content in the underlying rock and soil. The activity concentrations of ^{40}K, ^{232}Th, ^{226}Ra, and ^{210}Pb in the vegetation samples were 179.1 Bq kg^{-1}, 0.05 Bq kg^{-1}, 0.1 Bq kg^{-1}, and <0.02 Bq kg^{-1} and 312.7 Bq kg^{-1}, 0.1 Bq kg^{-1}, 0.2 Bq kg^{-1}, and 1.0 Bq kg^{-1} for food grains, respectively. The concentrations of stable elements Ca, Cr, Cu, Fe, K, Mg, Mn, Na, Pb, and Zn in the soil samples were 51.2×10^2, 150.0, 45.1, 367.4×10^2, 210.6×10^2, 11.0×10^2, 616.9, 248.8×10^2, 59.3 and 75.6 mg kg^{-1}, respectively. The concentrations of stable elements Ca, Cu, Fe, K, Mg and Na in the water samples were 16.6 mg L^{-1}, 1.1×10^{-2} mg L^{-1}, 9.9×10^{-2} mg L^{-1}, 3.2 mg L^{-1}, 45.1 mg L^{-1} and 71.7 mg L^{-1}, respectively. The concentration of K, Na, Ca, Mg, Cu, Cr, Fe, Mn, Zn, and Pb in the vegetables varied in the range of 17.5×10^2 – 33.3×10^2, 1.5×10^2 – 3.7×10^2, 1.3×10^2 – 7.2×10^2, 1.4×10^2 – 3.2×10^2, 0.7 – 2.4, 0.3 – 0.6, 33.0 – 80.1, 2.1 – 7.0, 2.0 – 7.5, and 0.1 – 0.5 mg kg^{-1} with the median values of 18.6×10^2, 3.3×10^2, 3.8×10^2,

2.7×10^2, 1.7, 0.4, 33.4, 2.2, 3.0 and 0.2 mg kg^{-1}, respectively. The median values of K, Na, Ca, Mg, Cu, Cr, Fe, Mn, Zn, and Pb in the food grains were 63.5×10^2, 5.5×10^2, 21.2×10^2, 7.8×10^2, 6.0, 4.1, 87.0, 29.8, 26.7, and 2.0 mg kg^{-1}, respectively. The results obtained in the present study were compared with the values reported for other regions of India and world.

Studies on

Studies on Radiation Level, Radionuclides and Trace Elements Concentration in Environmental Matrices around Gogi Uranium Mining Region

1.0 Introduction and significance of the study

Uranium ore is generally mined by underground and opencast methods. Uranium mining results in the generation of waste rocks, sub-ores, and mill tailings with low radioactive content. Mine water, runoff water from the ore and waste rock stockpiles, and from the tailings facility, may carry small amounts of radioactivity to the nearby aquatic system. The ^{222}Rn emanating from these materials has the potential to disperse in the atmosphere and result in increased inhalation dose. Therefore, a pre-operational study to establish the baseline database on radioactivity in different environmental matrices and trace elements concentration in a proposed Uranium mining region is essential. Such a study would help to assess radiological impact in the region during and after the mining operation.

Gogi region (16°43'28.6"N, 76°44'28.9"E) in Yadgiri district of north east Karnataka, South India has been identified by Atomic Mineral Department (AMD), Department of Atomic Energy (DAE) as a prospective uranium mining region. Hence, a detailed study was initiated with the aim of generating baseline database on radiation levels, radionuclide and trace elements concentration in the environmental matrices of Gogi region.

Baseline studies provide a range of valuable information which is critical to project decision-making and to predict impacts. This study is important as it would provide valuable baseline database which is essential to understand the long-term radiation hazard, if any, to the environment and population of the region due to the mining operations. In addition to these, baseline studies also help in identifying the critical components in the environment and critical samples and the most important radionuclide and stable element so that the necessary action can be carried out in the cases of emergency related to radiation protection. Such studies undertaken by autonomous and reputed institutions would have wider acceptance among the general

public and this would help in building public confidence in the mining and exploration activities for the development of the nation. Environmental samples (terrestrial, atmospheric, and aquatic samples) from 0-5 km (Core zone), 5-15 km (Buffer zone I), and 15-30 km (Buffer zone II) zones of Gogi region were collected regularly and analyzed for the concentrations of ^{40}K, ^{232}Th, ^{238}U, ^{226}Ra, ^{210}Pb, ^{210}Po, ^{137}Cs and stable elements. An extensive study on gamma absorbed dose rates were carried out. The ^{222}Rn, ^{220}Rn and their progeny concentrations in indoor and outdoor air and in the ground water was monitored regularly.

2.0 Aims and objectives

The main objective of the research study is to establish the database on baseline levels of radiation levels, and radionuclides and stable elements concentration in terrestrial, aquatic, and atmospheric environs of Gogi region. In particular, the study aims to generate a database on the following aspects:

- Ambient gamma absorbed dose to the population,
- Indoor and outdoor ^{222}Rn, ^{220}Rn and their progeny concentrations,
- Diurnal variation of ^{222}Rn concentration in air,
- Uranium, ^{226}Ra, and ^{222}Rn concentrations in the ground water,
- Activity concentration of radionuclides (^{40}K, ^{232}Th, ^{238}U, ^{226}Ra, ^{210}Pb, ^{210}Po and ^{137}Cs) in terrestrial, aquatic, and atmospheric environmental matrices and food materials,
- Estimation of population dose (external radiation dose and internal),
- A comparative study on different techniques for short term and long term measurement of ambient gamma absorbed dose rates, ^{222}Rn and progeny concentrations in indoor and outdoor environment, and
- Concentrations of trace elements (Na, K, Cu, Pb, Fe, Cr, Ca, Mg, Zn, and Mn) in terrestrial, aquatic, and atmospheric environmental matrices and food materials of the Gogi uranium mining region.

3.0 Overview of the work done

To start with, detailed digital maps of Gogi region, to locate sampling stations were prepared after obtaining the original maps of the region from the Survey of India, Bangalore. The study region was divided into 3 different zones: Core zone (0-5 km), Buffer zone I (5-15 km), and Buffer zone II (15-30 km) with Gogi site as the centre for each zone. Sampling stations for sampling terrestrial, aquatic, and atmospheric samples were identified using GPS

coordinates.

The sampling stations were identified and the samples were collected following standard procedures as outlined in EML[1] procedure manual (1983), IAEA (1989)[2] and BARC[3] procedure manual (BARC, 2008). The ambient gamma absorbed dose rates were measured in different locations using RDS-31 survey meter (Mirion, France). The gamma radiation levels were measured 1 m above the ground. The long term gamma absorbed dose rates were measured using the Thermo Luminous Dosimeters (TLD) supplied by BARC. A total of 24 indoor and 19 outdoor locations were identified for the TLD measurements. The exposure period of the TLDs in the field was 90 days. The comparative study of gamma absorbed dose rates measured by survey meter, TLDs and soil radioactivity were also carried out.

The ^{222}Rn progeny concentration in the outdoor air was measured by the Tsivoglou method[4]. In this method air samples are drawn through a filter paper at a flow rate of about 25 lpm for 15 minutes. The filter samples are then counted for alpha activity during 3 intervals of: 2-5 minutes, 5-20 minutes and 20-30 minutes. Long-term integrated measurements of ^{222}Rn and ^{220}Rn progeny concentrations were carried out by using Direct Radon Progeny Sensors (DRPS) and Direct Thoron Progeny Sensors (DTPS). These dosimeters, developed by BARC[5], were exposed to the indoor and outdoor environs for 90 days and after the exposure the dosimeters are retrieved and etched and the tracks were counted (Mishra and Mayya, 2008).

The concentrations of indoor and outdoor ^{222}Rn were measured using the AlphaGuard (Genitron, Germany). The AlphaGuard was placed in different locations for one full day in 60 min diffusion mode and the ^{222}Rn concentrations are noted. In addition to this, long term indoor ^{222}Rn concentration measurements were carried out by using pin-hole ^{222}Rn

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1 EML Procedure Manual, Edited by Herbert L. Volchok and Gail de Planque, 26th Edn.,Environmental Measurement Laboratory, 1983.

2 International Atomic Energy Agency (IAEA), 1989. IAEA/RCA. Measurement of Radionuclides in Food and Environment. Technical Report Series. 295. IAEA, Vienna.

3 Bhabha Atomic Research Centre (BARC), Standard Protocol for evaluation of environmental transfer factors around NPP sites. Edited: Hegde, A. G., Verma, P. C. and Rao, D. D., BARC, Mumbai, 2008.

4 Thomas. J.W. (1970). 'Modification of the Tsivoglou Method for radon daughters in air'. 'Health Physics' 19, 691.

5 Rosaline Mishra and Y. S. Mayya. Study of a deposition-based direct thoron progeny sensor (DTPS) technique for estimating equilibrium equivqlent thoron concentration (EETC) in indoor environment. Radiation Measurements, 43 (8), 2008, 1408-1416.

dosimeters. These dosimeters were placed in different dwellings for 90 days and after the exposure period they were retrieved and processed to determine the concentration[6].

Soil samples were collected from different sampling stations (during different seasons of the year) from all the three study zones. Samples of vegetables and different food grains grown in the region were also collected from the local market as well as from individual houses. The activity concentrations of ^{40}K, ^{232}Th, ^{238}U, ^{226}Ra, ^{210}Pb and ^{137}Cs in different samples was determined by gamma spectrometry[7] by employing either a 42% relative efficiency n-type (model GR4021) or a 38% relative efficiency p-type (model BE3825) HPGe detectors having carbon fiber windows and ultra low background cryostats (Canberra make, USA). The energy resolution of the detector was 2.1 keV at 1.33 MeV. The detectors were enclosed in a 10 cm thick low background graded lead shield to reduce the background. GENIE-2000 gamma spectroscopy software was used for data acquisition and analyses of the spectra. The detector efficiency calibration was performed using the IAEA quality assurance reference materials (RGU-238, RGTh-232, RGK-1 and SOIL-6). The IAEA quality assurance reference material (IAEA 307, sea plant ash) was used for efficiency calibration for the measurement of radionuclides concentration in the ashed samples of the vegetables. Soil samples were counted for 40,000 s and ashed samples of vegetables were counted for 60,000 s. Frequent intercomparison measurements were carried out with BARC and IAEA for quality assurance in the measurement techniques.

For the determination of the activity concentration of ^{210}Po in soil, the samples were digested using a closed type Microwave Digestion System (Milestone) and then the ^{210}Po present in the sample solution was deposited onto a silver disc through chemical deposition and the activity was measured using a ZnS (Ag) alpha counter[8].

The uranium concentration in water was determined using a microprocessor based laser fluorimeter. The ^{222}Rn concentration in the water was estimated by emanometry method[9]. The activity concentration of ^{226}Ra in water was determined by collecting about 20

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6 Mayya Y. S., Eappen K. P. and Nambi K. S. V., 1998. Methodology for mixed field inhalation dosimetry in monazite areas using a twin-cup dosimeter with three track detectors. Radiation Protection Dosimetry, 77 (3), 177-184.

7 Karunakara, N., Somashekarappa, H. M., Narayana, Y., Avadhani, D. N., Mahesh, H. M. and Siddappa, K. ^{226}Ra, ^{232}Th and ^{40}K concentrations in soil samples of Kaiga of south west coast of India. *Health Physics*, USA, No.5, pp. 470-476, 2001.

8 Karunakara, N., Avadhani, D. N., Somashekarappa, H. M., Narayana, Y. and Siddappa, K. Distribution and enrichment of ^{210}Po in the environment of Kaiga in south India. Journal of Environmental Radioactivity, 51, 349-362, 2000.

9 Raghavayya, M. A Study on the distribution of radon in uranium mines. BARC, Mumbai, India. BARC/I-452, 1977.

liters of water and subjecting it to pre-concentrating using MnO_2 powder. The MnO_2 precipitate was transferred to a 300 ml container and kept for 30 days to attain radioactive equilibrium between ^{226}Ra with its daughter products and then subjected to HPGe gamma spectrometry.

The concentrations of different trace elements were analyzed by employing Atomic Absorption Spectrometer (GBC, Australia). For this the samples were digested using a closed type Microwave Digestion System and then the digested samples, depending upon the elements to be analysed, were injected to either a Graphite furnace or to flame type AAS system. MERCK analar grade elements standards were used for the calibration of the AAS system.

4.0 Outline of the Thesis

The subject matter of the thesis has been divided into four chapters. The contents of these chapters are briefly outlined below.

Chapter 1. Introduction and literature survey

This chapter presents an introduction to the different sources of radionuclides and trace elements and their origin, behavior in the environment. It also discusses about the variation in the activity concentration of radionuclides and the resulting radiation exposure to the population of different regions of India and the world. The chapter also provides a detailed survey of the literature giving a glimpse of the work done by other investigators on radionuclide distributions in the environs of uranium mining regions in different parts of India and the world, and also presents details on reports published by the Health Physics Division, Bhabha Atomic Research Center (BARC), Mumbai, India and International regulatory bodies, such as, International Atomic Energy Agency (IAEA) and International Commission for Radiation Protection (ICRP). The importance of the study and the aims and objectives are also outlined in this chapter.

Chapter 2. Materials and Methods

This chapter presents the details of different techniques employed in this study for the measurement of radiation levels, radionuclide activity concentrations, and trace elements concentrations. The methodology adopted for identifying the sampling locations, and the collection and processing of samples prior to the analysis are presented. Details of the RDS-31 survey meter and Thermo Luminescent Dosimeters (used for the survey of gamma radiation levels) are presented in this chapter. The methods followed for the collection of

terrestrial, aquatic, atmospheric and food and diet samples are discussed. The analytical techniques employed for the determination of radionuclides and stable elements are also presented. The details of the HPGe gamma spectrometers (used for the measurements of radionuclide concentrations) and the flame and graphite furnace type Atomic Absorption Spectrometer systems[10] (used for the measurement of stable elements concentrations) are given in this chapter along with the details of the calibration of instruments, standardisation of methods, quality assurance**,** and the results of the inter-comparison measurements. Details of the other instruments used for the measurements of radionuclides (AlphaGuard, DTPS and DRPS, Standard Radon Monitor, Alpha counter, Laser fluorimeter, and ^{222}Rn bubbler) are also presented in this chapter.

Chapter 3. Results and discussions

This chapter presents the results and comprehensive discussions on gamma absorbed dose rates, indoor and outdoor ^{222}Rn, ^{220}Rn, and progeny concentrations in the air, activity concentrations of uranium, ^{226}Ra, and ^{222}Rn in water samples, activity concentrations of ^{40}K, ^{232}Th, ^{238}U, ^{226}Ra, ^{210}Pb, ^{210}Po, and ^{137}Cs in the soil and vegetation samples, activity concentrations of ^{7}Be, ^{40}K, ^{232}Th, ^{226}Ra and ^{210}Pb in air samples, concentrations of trace elements (Na, K, Cu, Ni, Pb, Fe, Cr, Ca, Mg, Zn, and Mn) in the soil water and vegetation samples. The results presented are for 273 samples, 259 water samples, and 15 vegetation samples. The results of radionuclides and trace elements concentration are analyzed with appropriate statistical tools. Frequency distribution, Box-Whisker plots, t-test and Wilcoxon matched pair tests of radionuclide and trace elements concentration in various matrices are presented. Correlation between radionuclides and trace elements with physico-chemical properties of the soil and water quality parameters were also studied. The results of radium equivalent concentrations, population dose, hazard indices, and dose due to the ingestion of radionuclides through air, water, and food are presented and discussed in this chapter. The results are also compared with those reported in literatures for other parts of India and the worldwide representative values reported by UNSCEAR[11], NCRP, USEPA, ICRP, and IAEA reports. Some of the important findings of the study are as under:

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10 Akhaya Kumar Patra, S. S. Wagh, A. K. Jain, A. G. Hegde. Assessment of daily intake of trace elements by Kakrapar adult population through ingestion pathway. Journal of Environmental Monitoring Assessment 169, (2010), 267–272.

11 United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Sources and effects of ionizing radiation. Report to the General Assembly with scientific Annexes. United Nations, New York, 2008.

- The median values of gamma absorbed dose measured by survey meter were 148 nSv h^{-1}, 116 nSv h^{-1} and 92 nSv h^{-1} for Core zone, Buffer zone I, and Buffer zone II, respectively and the overall median value was 115 nSv h^{-1}.
- The median values of gamma absorbed dose rates, measured using TLDs, were found to be 124 nGy h^{-1} for the indoor environment and 118 nGy h^{-1} for the outdoor environment.
- The gamma dose observed for the Gogi region was higher when compared to the worldwide average value (56 nGy h^{-1}; UNSCEAR, 2008) as well as all India average value (80.7 nGy h^{-1}; Mishra and Sadasivan, 1971 and 88.7 nGy h^{-1}; Nambi et al., 1987). The median value of dose rate observed for the Core zone is ~3 times higher when compared to the worldwide mean value.
- A good correlation was observed between the gamma dose rate values measured using TLD and portable survey meter. It was observed that the agreement between the two techniques is good for low dose values and the deviation increased at higher dose values.
- The median values of activity concentrations of ^{40}K, ^{232}Th, ^{238}U, ^{226}Ra and ^{210}Pb in the soil were 778.9 Bq kg^{-1}, 84.4 Bq kg^{-1}, 43.6 Bq kg^{-1}, 33.3 Bq kg^{-1}, and 44.3 Bq kg^{-1}, respectively.
- The median value of activity concentration ^{137}Cs in the soil was 0.9 Bq kg^{-1}.
- The activity concentrations of ^{238}U and ^{226}Ra in the soil of Gogi region were similar to the average value reported for India (29 Bq kg^{-1} for ^{238}U and 32 Bq kg^{-1} for ^{226}Ra; UNSCEAR 2008) and world (33 Bq kg^{-1} for ^{238}U and 32 Bq kg^{-1} for ^{226}Ra; UNSCEAR 2008).
- The ^{232}Th and ^{40}K activity concentrations in the soil of Gogi region were higher when compared to the average value reported for India and the worldwide average values.
- The study revealed highly non-uniform distribution of ^{232}Th and ^{226}Ra in Gogi region with activity concentrations in the soil varying significantly within a small area, which is due to the highly localized uranium mineralization. The mean values of ^{226}Ra and ^{232}Th activities were higher in the Core zone and lowest in Buffer zone II.
- The gamma absorbed dose rates (cosmic component not included) estimated from the activity concentrations of primordial radionuclides in the soil were found to vary in the range of 13.7–459.8 nGy h^{-1} with a median value of 102.0 nGy h^{-1}.

- The correlation studies showed that the dose estimated from the soil radioactivity is better correlated with the dose measured using the portable survey meter, when compared to those obtained from TLDs. Dose values estimated from soil radioactivity provide an underestimate, when compared to those measured in-situ at 1m from soil surface. The dose when measured in situ using the survey meter account for the non-uniform distribution of radionuclides as measurements are taken from many points within a location.
- The indoor and outdoor gamma dose values measured using survey meter and TLDs, showed a significant positive correlation with the activity concentrations of ^{40}K, ^{232}Th, and ^{226}Rain the outdoor soil which indicate that indoor gamma dose is largely governed by the radioactivity distribution in the surrounding soil. The indoor and outdoor doses were marginally higher in the winter, from November–February, when compared to other seasons.
- The activity concentration of ^{210}Pb varied in the range of 16.9 – 138.6 Bq kg^{-1} with the median value of 44.3 Bq kg^{-1}. The activity concentration of ^{210}Pb was lower than those reported for Kaiga (85.5 Bq kg^{-1}, Karunakara, 1997) and comparable with the values reported for Coastal Karnataka (6.42-43.24 Bq kg^{-1}, Siddappa et al., 1994).
- The activity concentration of ^{210}Po in the soil varied in the range of 21.0-190.7 Bq kg^{-1} with a median value of 48.1 Bq kg^{-1} and this is similar to those reported for other regions of India.
- The $^{226}Ra/^{238}U$ ratio varied in the range of 0.26 – 1.41 with a median value of 0.77 and this indicates removal of ^{226}Ra from the soil. The activity ratio less than 1 indicate a preferential leaching of ^{226}Ra with respect to ^{238}U from the surface soil.
- The median value of $^{210}Pb/^{226}Ra$ activity ratio indicated that these two radionuclides are in equilibrium in soils of Core zone and Buffer zone 1 with median values of 1.01 and 1.03 respectively.
- The activity ratio of $^{210}Po/^{210}Pb$ varied in the range of 0.80 – 2.18 with a median value of 1.28. The $^{210}Po/^{226}Ra$ ratio was near unity for the Core zone with a median value of 1.01, but the ratio deviated from unity for the Buffer Zone I and II.
- The $^{232}Th/^{238}U$ and $^{238}U/^{40}K$ ratios varied in the ranges of 0.23 – 1.32, and 0.02 – 0.13, respectively with the corresponding median values of 0.48 and 0.05.
- The median values of indoor equilibrium equivalent thoron concentration (EETC) and equilibrium equivalent radon concentration (EERC) in the air were 1.3 Bq m^{-3} and 8.3 Bq m^{-3}, respectively. For outdoor environment, these values were 0.4 Bq m^{-3} and 3.0

Bq m^{-3}, respectively.

- The uranium concentration in ground water varied in the range of <2.4 – 33199 mBq L^{-1} with a median value of 115.1 mBq L^{-1}., which is higher when compared to those reported for Indian cities.
- The ^{226}Ra activity concentration in water varied in the range of 19.5 - 10506 mBq L^{-1} with a median value of 52.6 mBq L^{-1}. This is similar to those reported for other regions of the world.
- The ^{222}Rn activity concentration in water varied in the range of 0.4-2115 Bq L^{-1} with a median value of 17.4 Bq L^{-1} for different sources of water (tube-well, open-well, stream/river and lake).
- The activity concentrations ^{238}U, ^{226}Ra and ^{222}Rn observed in one of the tube-well situated in Gogi village (about 100 m from the proposed mining site) was an order of magnitude higher when compared to that observed in other tube-wells of the region. The reason for this was the higher uranium and radium content in the underlying rock.
- The median values of ingestion doses due to the intake of uranium through water from tube-well, open-well, stream/river and lake water were 1.9 µSv $y^{-}1$, 2.0 µSv y^{-1}, and 0.55 µSv y^{-1}, 15.4 µSv y^{-1}, respectively.
- The median values of ingestion dose due to the intake ^{226}Ra through tube-well, open-well water were 6.0 µSv y^{-1}, 4.5 µSv y^{-1} and for river water (Bhima) was 3.4 µSv y^{-1}.
- The median value of inhalation and ingestion doses due to the consumption of water were 0.05 mSv y^{-1} and 0.08 mSv y^{-1} for tube-well and 6.2 µSv y^{-1} and 3.1 µSv y^{-1} for open-well. For stream/river water had median values of 1.3 µSv y^{-1} and 0.64 µSv y^{-1}, respectively where as those for lake water were 31.0 µSv y^{-1} and 15.7 µSv y^{-1}, respectively.
- The median values of dose observed due to the intake of radionuclides in water were higher when compared to the value reported for other regions of India and the world.
- The median values of activity concentrations of ^{7}Be, ^{40}K, ^{232}Th, ^{226}Ra and ^{210}Pb in the air samples were 3.7 mBq m^{-3}, 3.1 mBq m^{-3}, 1.8 mBq m^{-3}, 0.3 mBq m^{-3}, and 1.2 mBq m^{-3}, respectively.
- The median values of activity concentrations of ^{40}K, ^{232}Th, ^{226}Ra, and ^{210}Pb in the vegetables were 179.1 Bq kg^{-1}, 0.05 Bq kg^{-1}, 0.1 Bq kg^{-1}, and <0.02 Bq kg^{-1}, respectively and in food grain these had median values of 312.7 Bq kg^{-1}, 0.1 Bq kg^{-1},

0.2 Bq kg^{-1}, and 1.0 Bq kg^{-1}, respectively.

- The concentration of stable element Ca, Cr, Cu, Fe, K, Mg, Mn, Na, Pb, and Zn in the soil had median values of 51.2×10^2, 150.0, 45.1, 367.4×10^2, 210.6×10^2, 11.0×10^2, 616.9, 248.8×10^2, 59.3, and 75.6 mg kg^{-1}, respectively.
- The concentrations of stable elements Ca, Cu, Fe, K, Mg, and Na in the water samples were 16.6 mg L^{-1}, 1.1×10^{-2} mg L^{-1}, 9.9×10^{-2} mg L^{-1}, 3.2 mg L^{-1}, 45.1 mg L^{-1}, and 71.7 mg L^{-1}, respectively.
- The concentration of K, Na, Ca, Mg, Cu, Cr, Fe, Mn, Zn, and Pb in vegetables varied in the range of 17.5×10^2 – 33.3×10^2, 1.5×10^2 – 3.7×10^2, 1.3×10^2 – 7.2×10^2, 1.4×10^2 – 3.2×10^2, 0.7 – 2.4, 0.3 – 0.6, 33.0 – 80.1, 2.1 – 7.0, 2.0 – 7.5, and 0.1 – 0.5 mg kg^{-1} with the median values of 18.6×10^2, 3.3×10^2, 3.8×10^2, 2.7×10^2, 1.7, 0.4, 33.4, 2.2, 3.0, and 0.2 mg kg^{-1}, respectively.
- The median values of K, Na, Ca, Mg, Cu, Cr, Fe, Mn, Zn, and Pb in food grains were 63.5×10^2, 5.5×10^2, 21.2×10^2, 7.8×10^2, 6.0, 4.1, 87.0, 29.8, 26.7, and 2.0 mg kg^{-1}, respectively.

Chapter 4. Conclusions

This chapter summarizes the important results presented in chapter 3. The conclusions drawn from the study and the suggestions for the future studies in this area are also presented in this chapter.

Annexures

Since large number of samples were analysed from different sampling stations, presenting results for all individual samples in chapter 3 was difficult and therefore only summary of the results were presented in chapter 3. This section provides results on gamma absorbed dose rates in air, radionuclide and trace elements concentrations in the soil and water samples collected from individual sampling location. The results presented can be broadly classified as:

i. Results of gamma absorbed dose rates in air (2 tables).

ii. Results of radionuclide concentrations in the soil and gamma absorbed dose rates from primordial radionuclides (8 tables).

iii. Results of indoor and outdoor ^{222}Rn, ^{220}Rn and their progeny concentration in air measured by Tsivoglou method and Direct Progeny Sensors (4 tables).

iv. Results of radionuclide concentrations in air (1 table).

v. Results of uranium, ^{226}Ra and ^{222}Rn concentrations in water samples (6 tables).

vi. Results of trace elements concentrations in the soil and water samples (22 tables).

5.0 Research Publications in Journals, National and International Conferences related to the thesis work

(i) Journals

1. **Yashodhara, I.**, Karunakara, N., Sudeep Kumara, Rudramurthy and Tripathi, R. M. Radiation levels and radionuclide distributions in soils of Gogi region, a proposed uranium mining region in North Karnataka. Journal of Radiation Protection and Environment, Vol. 34, Issue 4, pp. 267-269, 2012.

2. Karunakara N., **Yashodhara I**., Sudeep Kumara K., Tripathi R. M., Chougaonkar M. P., Menon S. N. and Sonal Kadam. Assessment of Ambient Gamma Dose Rate around a Prospective Uranium Mining Area of South India - A Comparative Study of Dose by Direct Methods and Soil Radioactivity Measurements. (**Paper Accepted**, **Results in Physics; Manuscript No. RINP-D-13-00104R1**).

(ii) International and National conferences

3. Karunakara, N., **Yashodhara I**., Chetan Rao., Ujwal and Thripati R. M. Studies on ^{222}Rn and ^{238}U in Ground waters of Gogi region, a prospective uranium mining region. 7^{th} International Conference on High Levels of Natural Radiation and Radon Areas (7HLNRRA), Nov. 24-26, 2010, Mumbai.

4. Karunakara, N., Mishra, R., **Yashodhara, I**., Tripathi, R. M., Prajith, Sapra, B. K., and Mayya, Y. S. Indoor and outdoor ^{222}Rn and ^{220}Rn progeny measurements in Gogi Region, a prospective uranium mining area, using direct progeny sensors. 7^{th} International Conference on High Levels of Natural Radiation and Radon Areas (7HLNRRA), Nov. 24-26, 2010, Mumbai.

5. **Yashodhara, I**., Karunakara, N. and Tripathi, R. M. Radioactivity and radionuclide distributions in soils of Gogi region, a proposed Uranium mining region in North

Karnataka. Proceedings of 30th IARP National Conference (IARPNC-2012), March 15-17, 2012, Mangalore University.

6. **Yashodhara, I**., Sudeep Kumara, Karunakara, N., and Tripathi, R. M. Activity concentrations of ^{226}Ra and ^{238}U in water samples and estimation of radiation dose around the proposed uranium mining region in Gogi. Proceedings of 19th National Symposium on Radiation Physics (NSRP-19), Chennai, September 26-29, 2012.

7. **Yashodhara, I**., Karunakara, N., Sudeep Kumara and Tripathi, R. M. Concentration of ^{210}Pb and ^{210}Po in soil samples around Gogi Uranium mining region. Proceedings of 2nd International Conference on Po and radioactive Pb isotopes (INCO-PoPb-2013), Mangalore University, February 10-13, 2013.

8. **Yashodhara I.,** Sudeep Kumara K., Rosaline Mishra., Mayya Y. S., Tripathi R. M. and Karunakara N. Radon and thoron concentrations in indoor air of Gogi region, a proposed uranium mining region of north Karnataka. Proceedings of SSNTDs-18, Faridabad, October 18-20, 2013.

9. **Yashodhara I.,** Sudeep Kumara K., Karunakara N. and Tripathi R. M. Radiation levels and radionuclide distributions in terrestrial, atmospheric and aquatic environs of Gogi uranium mining region of North Karnataka. NAC-V, Mumbai, 20-24th January 2014.

Place: Mangalagangothri (Yashodhara I.)

Date: 21.02.2014 Research Student

Place: Mangalagangothri (Dr. Karunakara N.)

Date: 21.02.2014 Research Guide